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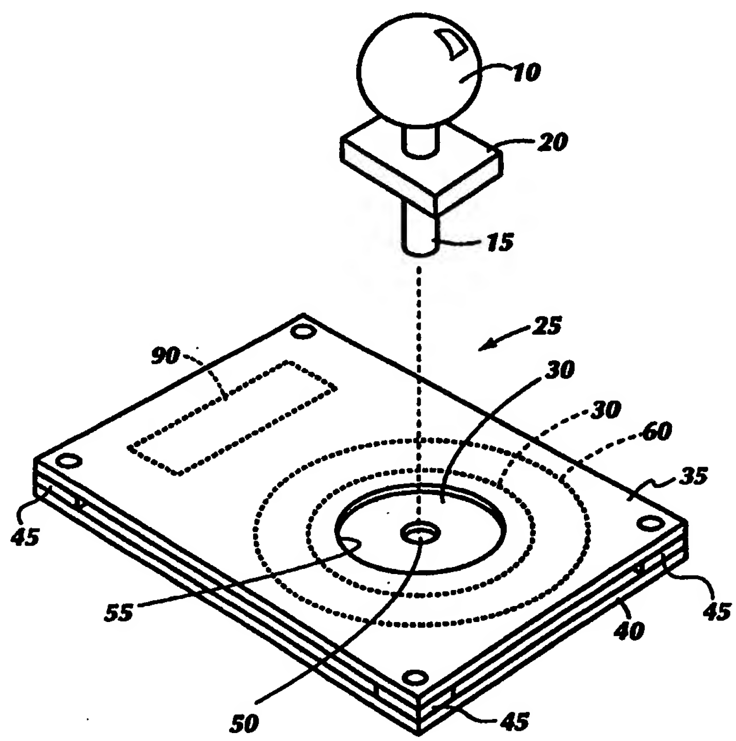
(54) Title: POSITION SENSING METHOD AND APPARATUS

(57) Abstract

A position sensing device for use on determining the location of a control handle or joy stick includes a dielectric element movable between a pair of spaced-apart printed circuit boards which have formed thereon a plurality of capacitors surrounding a central axis. As the control handle moves, the dielectric element, preferably a disk formed of Teflon®, covers more or less of the area between the individual capacitor elements, causing the capacitance of each to change. The capacitors are preferably arcuate segments on at least one of the boards which are radially spaced and surround from a reference location. In one embodiment, two sets of radially spaced apart arcuate segments are included to provide redundancy. The capacitor elements may be embedded in the boards to minimize wear. A capacitance measuring circuit determines the actual capacitance of each capacitor and a position determining circuit uses the capacitance values to determining the actual position of said control element with respect to the central axis.



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POSITION SENSING METHOD AND APPARATUS

BACKGROUND OF THE INVENTION

This invention relates to a control mechanism, such as a joy stick, that includes a position sensing device, particularly an X-Y position sensing device. This invention may be used in connection with a control handle that controls the operation of a fork lift truck or other vehicle, or it might be used in other environments, such as game controllers.

Prior art position sensing devices often use potentiometers or other similar devices to sense the location of the control mechanism. These devices are often mechanically complicated and are subject to wear, and the senors itself is subject to both mechanical and electrical failure. What is needed is a position sensor that is simple, requiring an uncomplicated mechanical interface with the control mechanism, and not subject to mechanical wear or electrical failure.

SUMMARY OF THE INVENTION

The present invention is directed to a position sensing device that employs capacitors to determine the position of a control handle. The capacitors are formed on a planar surface, thus requiring only the simplest of mechanical interfaces with a control handle. The capacitor elements themselves are protected from wear.

In the present invention, an essentially frictionless and wear resistant control handle position sensing apparatus includes a planar dielectric disk of Teflon® or other similar material that is moved by the control handle between parallel, preferably flat plates formed on and radially spaced from a reference location on spaced-apart printed circuit boards. The plates form capacitors whose capacitance changes according to the area of the disk placed between the plates. A position determining circuit compares the capacitance values of the various plates to provide an output indicating the actual position of the disk and therefore the position of the control handle.

It is therefore an object of this invention to provide a position sensing device for determining the position of a control mechanism comprising first and second spaced-apart support elements; at least two capacitors carried by the support elements and arranged about a reference location; each of the capacitors comprising a plate formed on one support element opposite a plate formed on the other support element; and a dielectric element movable between the capacitor elements by a control mechanism, the dielectric element, as it is moved relative to the capacitors, changing the capacitance of each.

It is a further object of this invention to provide a method of determining the position of a control mechanism in an X- and Y- plane comprising the step of forming a plurality of capacitor elements on parallel first and second spaced-apart support elements around a reference location; placing a dielectric element between the capacitor elements, the dielectric element being movable between the capacitor elements by a control mechanism, the dielectric element, as it is moved relative to the capacitors, changing the capacitance of each; measuring the capacitance of each of the capacitor elements; and determining the position of the dielectric element, and thus the position of the control mechanism, as a function of the capacitance measurement.

Other objects and advantages of the invention will be apparent from the following description, the accompanying drawings and the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is perspective view showing the position sensing apparatus of the present invention attached to a control handle;

Fig. 2 is an exploded perspective view of the present invention;

Fig. 3 is a plan view of the capacitor elements or plates formed on one printed circuit board;

Figs. 4 and 5 show the relationship of a dielectric disk to the plates on the printed circuit board of Fig. 3;

Fig. 6 is a plan view of another embodiment of the invention;

Fig. 7 is a simplified electrical block diagram of the present invention;

Fig. 8 and 9 illustrate another embodiment of the invention. Fig. 8 shows a template for limiting the direction of travel of a control mechanism. Fig. 9 is a plan view of a printed circuit board with one component of a multiple plate capacitor formed thereon;

Fig. 10 is an exploded, perspective view of a further embodiment of the invention;

Fig. 11 is a cross-sectional view of a portion of the dielectric disk, taken along lines 11-11 of Fig. 10; and

Fig. 12 is a perspective view of still another embodiment of the invention.

DETAILED DESCRIPTION

Referring now to the drawings, and particularly to Figs. 1 and 2, a control mechanism, such as a control handle or joy stick, shown at 10, includes a movable shaft 15 which extends through a pivot assembly 20. The lower end of the shaft 15 extends into a position sensing apparatus 25, and specifically into a dielectric element or disk 30 that is placed between a pair of printed circuit boards or support members 35 and 40 that are separated by spacers 45. The spacing between the boards is sufficient to permit free movement of the element 30 while limiting its movement in a direction normal to the plane of the boards. While the dielectric element 30 is shown as a disk, it could take other shapes.

The shaft 15 extends into an opening 50 formed in the dielectric disk 30 to position the disk relative to the printed circuit boards under the control of the handle 10. The movable dielectric disk 30 is preferable made of Teflon® or some other wear resistant dielectric material. While an opening 50 is shown in the disk to receive a component of the control handle, other types of connection mechanisms could be provided for connecting the control handle to the disk 30.

In the exploded view of Fig. 2, the components of the position sensing apparatus are shown in more detail. The support member or printed circuit board 35 has formed therein an opening 55 through which the shaft 15 can extend and move about without the shaft touching the walls of the opening 55. A capacitor element or plate or receiving pad, shown as a circular copper plate 60, is preferably formed on an intermediate layer of a multi-layer printer circuit board. In practice, while the plate 60 is shown as circular, it could also be square, or it could have the same configuration as the plates formed on the board 40.

The support structure or printed circuit board 40 includes a plurality of capacitor elements in the form of a plurality of electrically isolated plates or arcuate segments P1 - P8, which are placed in concentric rings centered on a reference location 75 and which extend outwardly from a central opening 70. The center of the opening is concentric with a reference location 75, about which the position of the end of the shaft 15 will be measured. The opening 70 is preferably the same diameter as

the opening 55 and is coaxial therewith. The plates P1 - P8 are radially spaced from the reference location and formed on an intermediate layer of a multi-layer printer circuit board. A capacitance measuring circuit 80 (Fig. 7) may conveniently be placed on the outside surface of one of the printed circuit boards and the individual plates connected thereto by printed circuit traces (not shown).

The plates 60 and P1 - P8 may be placed in intermediate layers of a multi-layer printed circuit board to protect these components from wear due to the movement of the disk 30.

As illustrated in Fig. 3, inner plates P1 - P4 are electrically conductive arcuate segments that are carried by support element 40 and are radially spaced from the reference location 75. These plates form a ring having an inside diameter radially spaced from the reference location by a first predetermined distance, and an outside diameter. In this embodiment, the segments extend radially outwardly from the inner edge of the opening 70. A space 77 separates the plates P1 - P4 from arcuate segments or plates P5 - P8 which form a separate ring, the inside diameter of which is radially spaced from the reference location 75 by a second predetermined distance.

The arcuate segments are shown as encompassing slightly less than a 90° arc, with only a thin space separating one arcuate segment from another. While four arcuate segments are shown in each of the inner and outer rings, it is to be understood, however, that for the purpose of determining the X- and Y-location of the disk 30, at least three segments would be necessary, and more than four could be used, if desired. In the preferred embodiment, the total circumferential extent of the segments in both rings or bands is approximately 360°.

As shown in the Fig. 3, the dielectric disk 30 preferably has a diameter that approximately equals the outside diameter of the plates P1 - P4, and is therefore slightly smaller than the inside diameter of the segments P5 - P8. In fact, it is preferred that the diameter of the disk 30 be centered in the space 77. Thus, when the disk 30 is centered on the reference location 75, it covers each of the plates P1 - P4 equally and completely, but it does not cover any part of the plates P5 - P8. On the other hand, if the disk were off center, then one or more of the plates P1 - P4

would be uncovered to some extent. Upon initial power up of the apparatus, the actual position of the disk can be determined and compensated for electronically.

In Fig. 4, the disk 30 is shown centered, the plates P1 - P4 are covered entirely while none of the plates P5 - P8 is covered. The disk 30 is shown as being the same diameter as the outer edges of the plates P1 - P4. This has the advantage of simplified calibration of the sensor; however, it is not strictly necessary in order to practice this invention. In Fig. 5, the disk 30 is shown as being moved to the left, thus uncovering plate P2, partially uncovering plates P1 and P3, and partially covering plates P5, P7 and P8.

While two sets of concentric plates P1 - P4 and P5 - P8 are shown, the apparatus could also be constructed with a single set of plates. However, by using two sets as shown, the redundant plates P1 - P4 insure an accurate cross-comparison with the primary plates P5 - P8, thus eliminating the need for "home" or "center" switches.

In the embodiment of Figs. 1-5, a dead band, that is, a region which is insensitive to movement of the control handle or joy stick, is formed by a the space 77 between the inner ring (segments P1 - P4) and the outer ring (segments P5 - P8), and by making the diameter of the disk 30 equal to the radial distance between the these two rings. Thus, the disk has room to move before it would affect the capacitance of either sets of capacitor segments. Alternatively, the disk could be made larger or smaller, and a dead band created electronically.

In the embodiment of Fig. 6, plates P9 - P12 are similar to the plates P5 - P8 of Fig. 3, except that they extend radially outwardly from the inner edge of the opening 70. When the disk 30 is centered, as shown in Fig. 6, each of the plates P9 - P12 is partially covered substantially equally. Upon initial calibration of the position sensor, the actual capacitance of each capacitor that the plates P9 - P12 form with plate 60 is recorded and used later to compensate for any unequal coverage of the plates, or variations in capacitance, even though the control handle 10 is in its neutral position.

In the simplified electrical block diagram of Fig. 7, the plates P1 - P8 (or plates P9 - P12) are each connected to a capacitance measuring circuit 80 by a printed

circuit trace, as is the pad 60 on the opposite side of the disk 30. As the disk moves between each of the plates P1 - P8 (or plates P9 - P12), it causes a change in the value of the capacitances as measured on the lines from the plates to the capacitance measuring circuit 80. These changes in capacitance are due to a change in the dielectric constant between the plates caused by the presence of the disk. The output of the capacitance measuring circuit is applied to a position determining circuit 85 whose output provides X- and Y-position information based on the capacitance values of each of the plates P1 - P8 (or P9 - P12 of Fig 6). Both circuits 80 and 85 may be mounted either on member 35 or 40 in the area designated 90 (Figs. 1 and 2).

The capacitance measuring circuit may employ the principles of dielectric measurement embodied in U.S. Patent 5,406,843 which is incorporated by reference herein. Each plate P1 - P8 is pulsed sequentially and repeatedly, and the energy transferred to the plate 60 is measured and averaged. The energy transferred is a function of the capacitance, which in turn is determined by the area of coverage of the disk 30. Also, the sensor can be calibrated by measuring the capacitance with and without the disk 30 being present. Other capacitance measuring techniques may also be used.

The principles of the present invention can also be used as a proportional control and switching device, as shown Figs. 8 and 9. In this embodiment, a printed circuit board 140 has formed thereon a plurality of electrically isolated plates or capacitor components A - H. Not shown is an opposing capacitor (or receiving) plate on a printed circuit board, which may be similar to plate 60 on board 35 (Fig. 2).

An opening 170 is formed in the center of the board 140 to permit free movement of an extension of a control shaft, which would be similar to shaft 15 (Fig. 1). The control shaft (not shown) extends into opening 150 formed at the center of a dielectric disk 130. The opening 150 is approximately the same diameter as the shaft. While a circular disk 130 is shown, a square dielectric element may be used since the direction of travel of the element is limited by a template, as shown in Fig. 8.

In Fig. 8 the upper printed circuit board 135, or a separate plate, if desired, has

two elongated guide slots 137 and 138 formed therein to restrain the movement of the control shaft to orthogonal or right angle movement. Alternatively, the opening 170 could include the guide slots.

Each of the plates A - D may function as proportional control sensors, that is, as the dielectric disk 130 is moved from its neutral position, a change of capacitance results from a change in the area of coverage by the disk. Plates RA - RD are redundant plates which may be used to determine the center position of the disk 130, thus again eliminating the need for "home" switches.

As shown, plates RA - RD are completely covered only when the disk 130 is in its central position; in all other positions, the plates RA - RD are unequally covered. The disk 130 is represented in its center position by the dashed line 150, in its uppermost position (as viewed in Fig. 9; actually the device may be in any position relative to the horizon) by the partial dashed line 152, in its extreme right position by the partial dashed line 154, in its extreme lower position by the partial dashed line 156 and in its leftmost position by the partial dashed line 158. Because of the restraint provided by the template of Fig. 8, and the shape of plates C and D, when the disk 130 is moved up or down, only plates A or B will be involved; there will be no effect on the capacitance of plates C and D. Similarly, when the disk 130 is moved to the right or left, only plates C and D will be affected.

Plates E and F and plates G and H are pairs of plates which act as switches in this embodiment of the invention. Associated with each plate pair is an actuator 200 that is biased away from the plates by spring 205. A push button 210, or other similar element, extends outwardly and may be manually actuated to move the actuator, which is also preferably made of Teflon®, or other similar material, between the plates G -H and the opposing plate. A pair of plates is used in this embodiment to maximize the change in capacitance.

The apparatus shown in Figs. 8 and 9 may be placed near or in the head of the control handle 10. In this embodiment, plates A - D may function as proportional control elements, controlling such functions on a lift truck as fork tilt, side movement, and reach, while plates E and F and G and H could act as simple on-off switches

controlling the horn, for example.

Another embodiment of this invention is shown in Figs. 10 and 11. In this embodiment, the apparatus is basically square to conserve space. Fig. 10 is an exploded view to show the various components of the apparatus, but it is to be understood that the components will be brought into intimate contact in its final form.

The apparatus includes an upper support member 240 which has formed therein a central circular opening 255 through which the end of a control shaft 15 may extend and move about without touching the walls thereof. A plurality of arcuate segments or plates P1 - P8 (elements P3 and P4 are not shown due to the broken-away portion of member 240) forming one element of the capacitors are mounted on the upper surface of the member 240 and perform the same function as previously described. The other capacitor element is shown as a square electrically conductive plate C1. The shaft 15 is received into a socket 232 formed in the dielectric member 230. As shown in Fig. 11, the shaft 15 extends only into the socket; it does not extend beyond the bottom surface of the dielectric member.

Below the dielectric member 230 is a four layer printed circuit board 235 with layers of fiberglass labeled F1 - F4. Between layers F1 (235) and F2 is capacitor element C1, or return plate 260, in the form of a copper cladding. Element C1 corresponds to element 60 of Figs 1,2 and 7. A spacer 245 separates boards 235 and 240 to provide the space necessary for free but vertically restrained movement of the dielectric disk 230.

Element C2 is a common ground element located between layers F2 and F3, which provides isolation from the capacitor elements mounted above. Element C3 is a cladding between layers F3 and F4, which is etched to provide the circuit traces for the interconnection of the electrical components P1 - P8 and C1 or 260 used in the capacitance measurement circuit to the capacitance measurement circuit 80. Element C4 is also a cladding which is etched to provide additional circuit traces for the surface mounted components comprising the capacitance measurement circuit and position determining circuit, which are mounted on the underside (and thus not shown) of the apparatus. The copper segments on the upper board 240 are

connected to the circuit mounted on element C4 by means of an feed-through interconnection, shown generally at 270. Because of the electrical isolation provided by the element C2, the entire assembly, including the capacitance measuring and position determining circuit, can be contained in a small, compact device.

The device of Fig. 12 is similar to Fig. 10 except that the upper board 241 is not provided with an opening. Rather, the dielectric element 236 is attached to an arm 237 that extends outwardly through one side of the apparatus, between members 235 and 241, where the end 238 thereof may be connected to a control element, not shown.

While the form of apparatus herein described constitutes a preferred embodiment of this invention, it is to be understood that the invention is not limited to this precise form of apparatus and that changes may be made therein without departing from the scope of the invention, which is defined in the appended claims.

1. A position sensing device for determining the position of a control mechanism relative to a reference location, said device comprising:

first and second spaced-apart support elements;

at least two capacitors carried by said support elements and arranged about the reference location; each of said capacitors including two elements, namely an electrically conductive plate formed on one support element opposite an electrically conductive plate formed on the other support element; and

a dielectric element movable between said capacitor elements by a control mechanism, said dielectric element, as it is moved relative to said capacitors, changes the capacitance of each.

2. The position sensing device of claim 1 wherein said capacitors are formed by at least two plates formed on one support element and a single plate formed opposite on the other support element.

3. The position sensing device of claim 1 wherein said capacitors are arcuate segments equally and radially spaced from the reference location.

4. The position sensing device of claim 1 wherein said capacitors include at least three arcuate segments on one of said support elements radially spaced from the reference location.

5. The position sensing device of claim 1 wherein said capacitors include four arcuate segments radially spaced from the reference location.

6. The position sensing device of claim 1 including two sets of capacitor, a first set comprising four arcuate segments in a ring radially spaced from the reference location by a first predetermined distance, and a second set comprising four arcuate segments in a ring radially spaced from the reference location by a second predetermined distance.

7. The position sensing device of claim 6 wherein said dielectric element is a circular disk having a radial dimension slightly less than said second predetermined distance.

8. The position sensing device of claim 6 wherein each of the arcuate segments are electrically separated from each other and wherein each of said arcuate segments encompasses slightly less than a 90° arc.

9. The position sensing device of claim 1 wherein said dielectric element is a circular disk.

10. The position sensing device of claim 1 wherein a circular opening is formed in at least one of said support elements, the center of said opening being concentric with said reference location, and wherein said capacitors surround said opening.

11. The position sensing device of claim 10 including a plurality of arcuate segments forming capacitor plates on at least one support element, said arcuate segments being formed in a pair of concentric rings surrounding said circular opening.

12. The position sensing device of claim 10 wherein said dielectric element, when in a central position, is clear of said capacitors.

13. The position sensing device of claim 10 wherein said dielectric element, when in the central position, covers each of the capacitors equally.

14. The position sensing device of claim 10 further including a second set of capacitors which are equally covered only when the dielectric element is in its central position.

15. The position sensing device of claim 1 wherein said support elements are planar and parallel to each other.

16. The position sensing device of claim 1 wherein said capacitors are mounted on planar printed circuit boards.

17. The position sensing device of claim 1 wherein said plates of said capacitors are embedded in said support elements.

18. The position sensing device of claim 1 wherein said dielectric element is formed of Teflon®.

19. The position sensing device of claim 1 further including a guide to restrain the direction of travel of the dielectric element.

20. A position sensing device for determining the position of a control mechanism relative to a reference location, said device comprising:

first and second spaced-apart support elements;

a plurality of capacitor elements carried by said support elements, said capacitor elements comprising:

a plurality of electrically conductive arcuate segments carried by one of said support elements and radially spaced from the reference location, said arcuate segments forming a first ring having an inside diameter and an outside diameter, and

at least one electrically conductive plate carried by the other of said support elements; and

a dielectric element movable between said capacitor elements by a control mechanism, said dielectric element, as it is moved relative to said capacitors elements, changes the capacitance of each.

21. The position sensing device of claim 20 wherein said dielectric element is a circular disk having an outside diameter less than the inside diameter of said arcuate segments.

22. The position sensing device of claim 20 further including

a second plurality of capacitor elements, said capacitor elements comprising :

a plurality of electrically conductive arcuate segments carried by one of said support elements and radially spaced from the reference location, said arcuate segments forming a second ring having an inside diameter and an outside diameter, and

at least one electrically conductive plate carried by the other of said support elements;

the outside diameter of said second ring being smaller than the inside diameter of said first ring; and

wherein said dielectric element is a circular disk having an outside diameter approximately equal to the outside diameter of said arcuate segments of said second capacitor elements.

23. The position sensing device of claim 20 wherein at least one of said support elements includes an opening through which the control mechanism extends to engage said dielectric element.

24. The position sensing device of claim 20 wherein the control mechanism is attached to an arm which extends between and beyond said support elements.

25. The position sensing device of claim 20 wherein said plurality of arcuate segments comprising said capacitor elements includes at least three segments.

26. The position sensing device of claim 20 wherein said plurality of arcuate segments comprising said capacitor elements includes four segments, each encompassing slightly less than a 90° arc.

27. A method of determining the position of a control mechanism in an X- and Y- plane comprising the steps of:

forming a plurality of capacitor elements on parallel first and second spaced-apart support elements around a reference location;

placing a dielectric element between said capacitor elements, the dielectric element being movable between said capacitor elements by the control mechanism, said dielectric element, as it is moved relative to said capacitors, changes the capacitance of each;

measuring the capacitance of each of said capacitor elements; and

determining the position of the dielectric element, and thus the position of the control mechanism, as a function of the capacitance measurement.

28. The method of claim 27 further including the steps of:

forming a circular opening in at least one of the support elements with its center concentric with the reference location;

forming the capacitor elements as a plurality of arcuate segments placed in a ring radially spaced from and surrounding the circular opening; and

forming the dielectric element as a circular disk having a diameter which covers the arcuate segments equally only when the control element is in a neutral or center position.

29. The method of claim 28 further including the steps of :

forming first and second capacitor elements as a pair of concentric rings each comprising a plurality of arcuate segments; and

making the diameter of the dielectric disk equal to the maximum diameter of the innermost capacitor ring.

Fig. 1

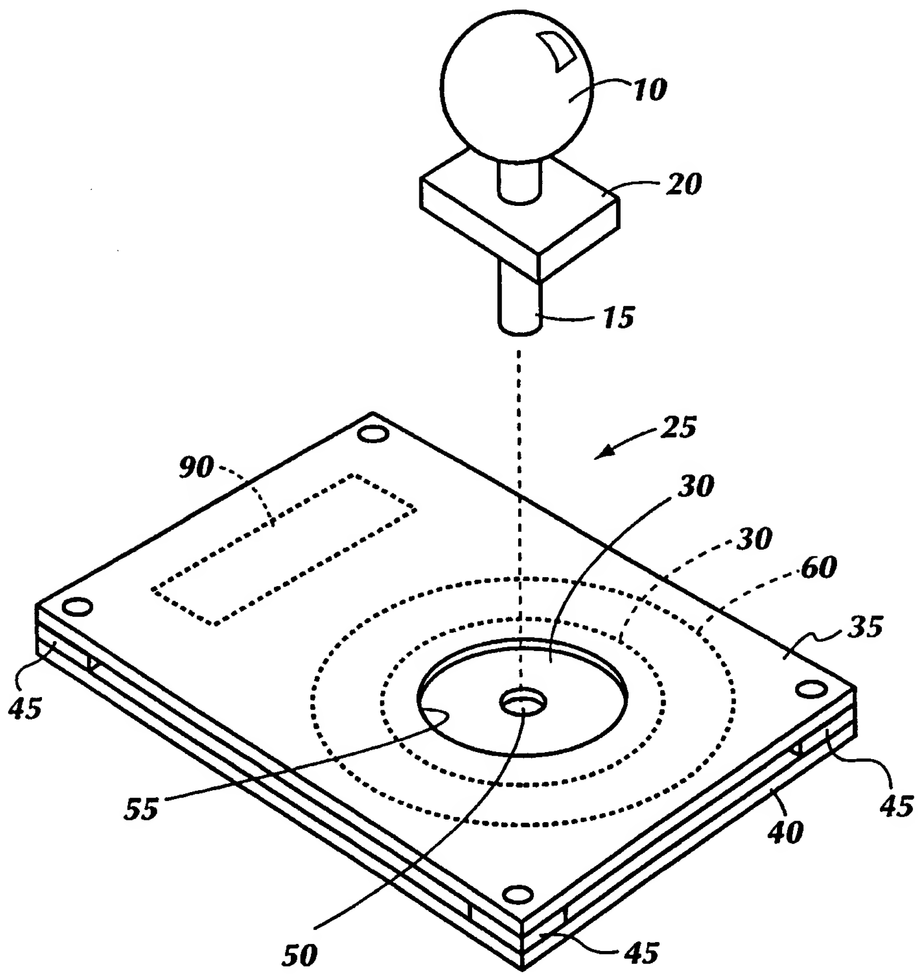

Fig. 2

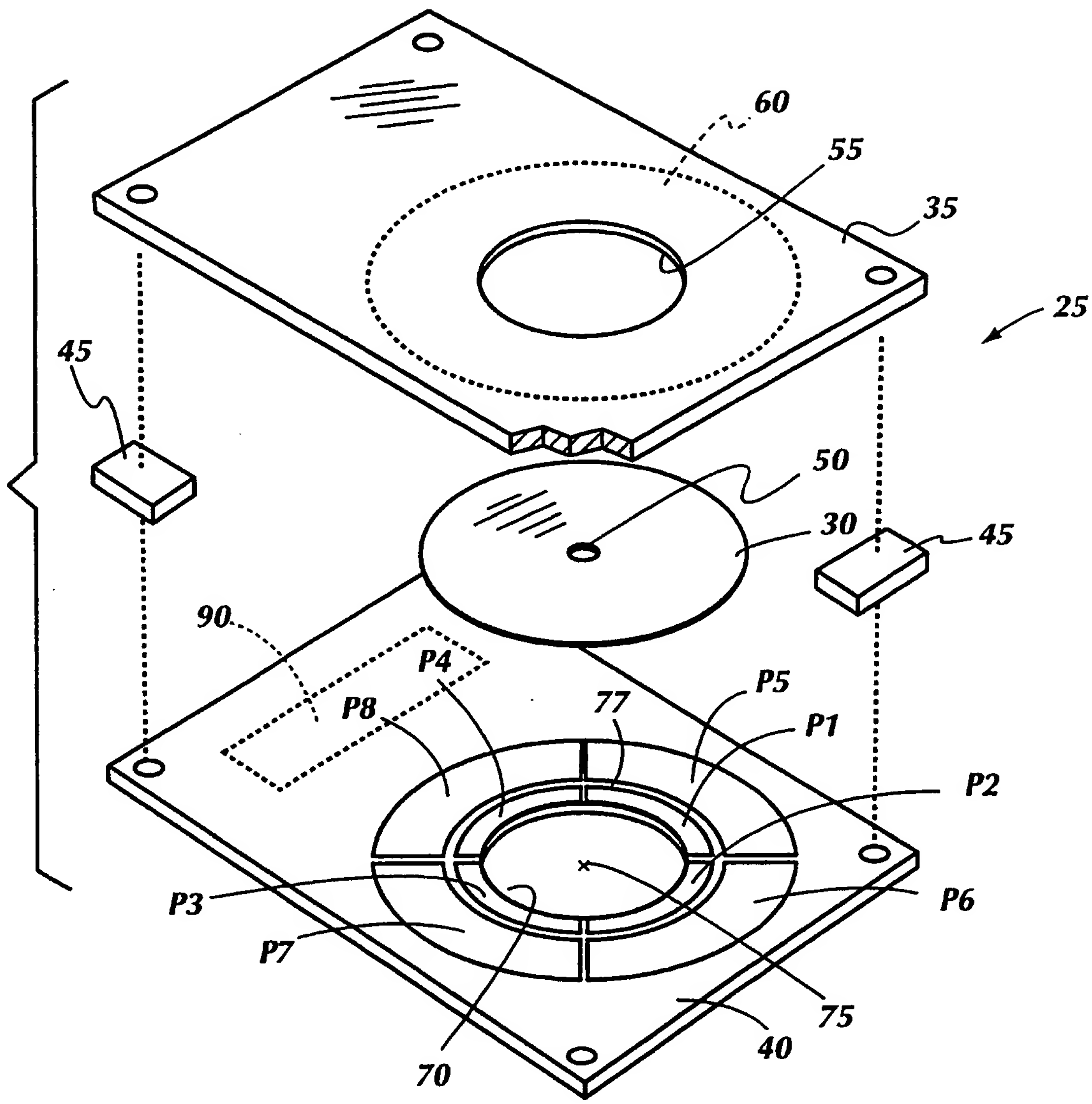

Fig. 3

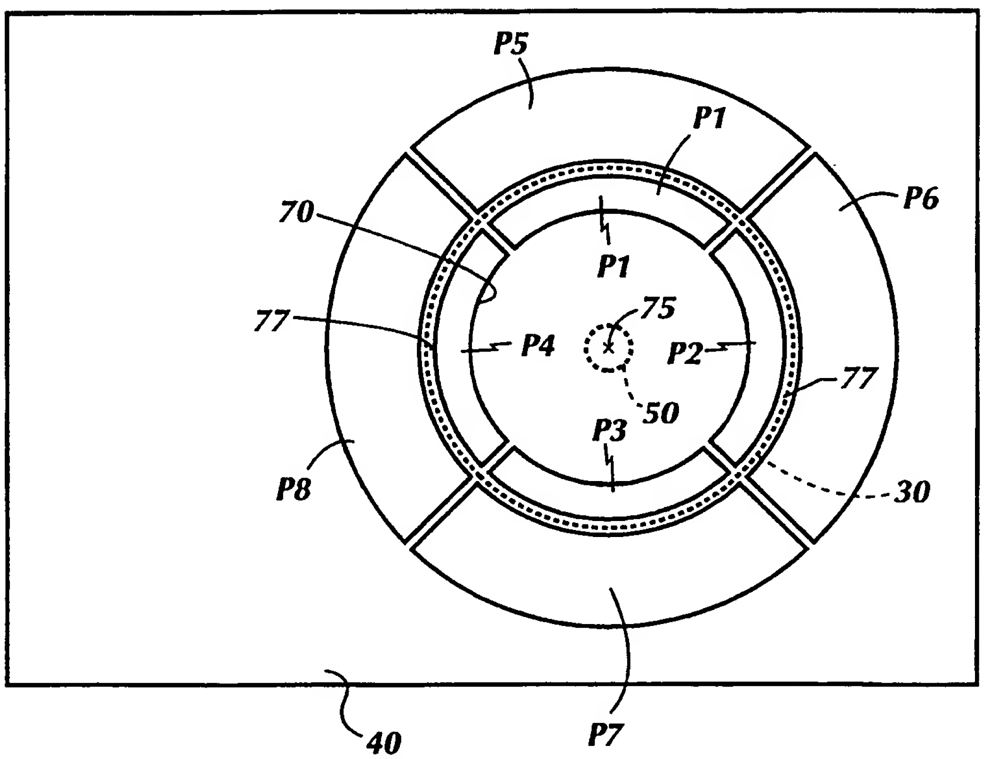

Fig. 4

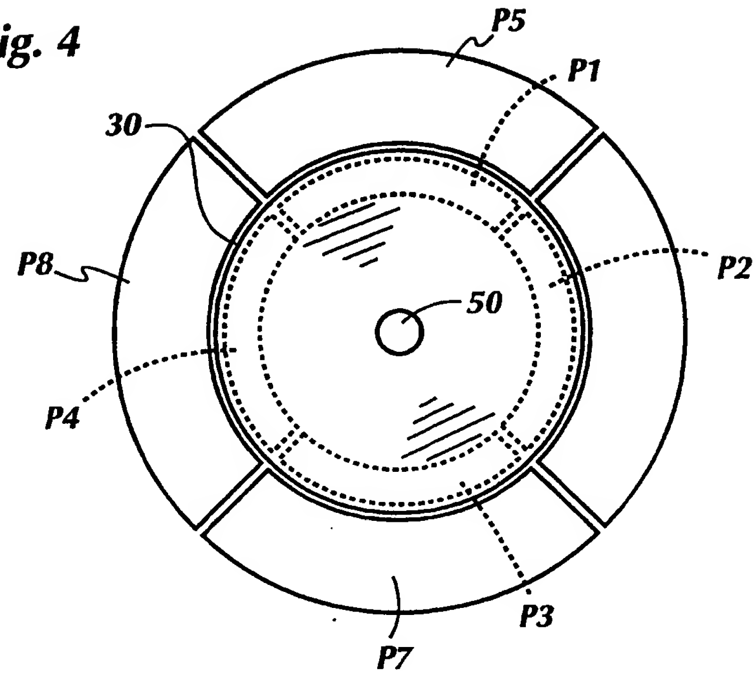

Fig. 5

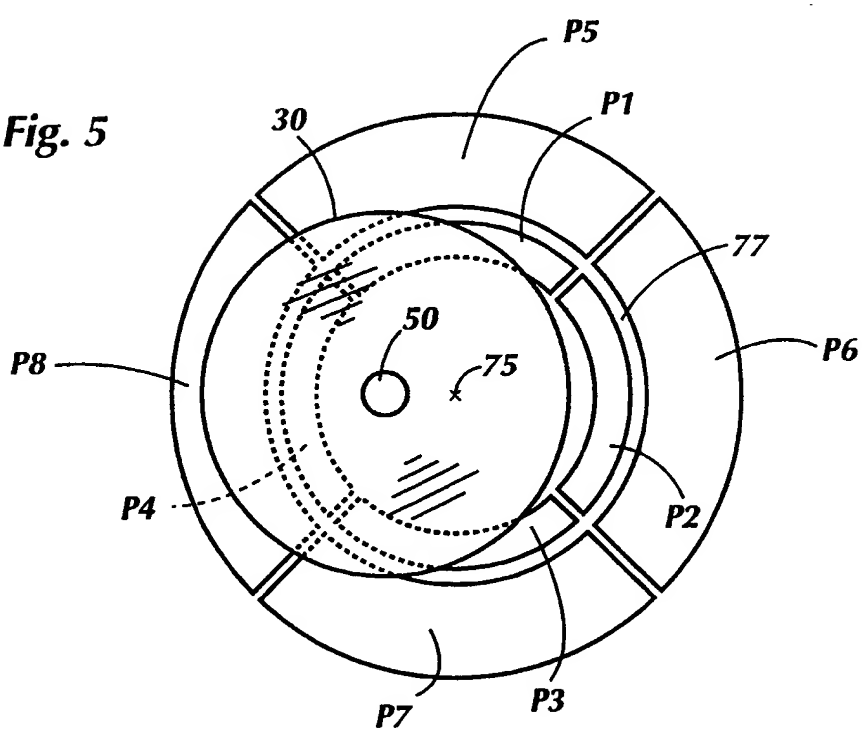

Fig. 6

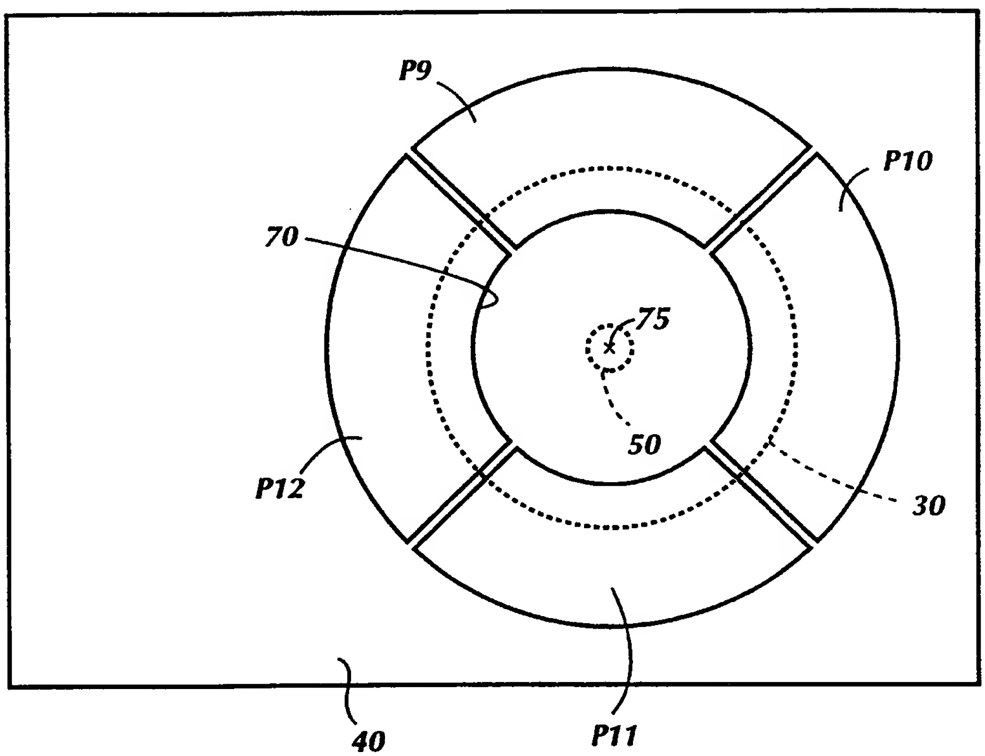

FIG. 7

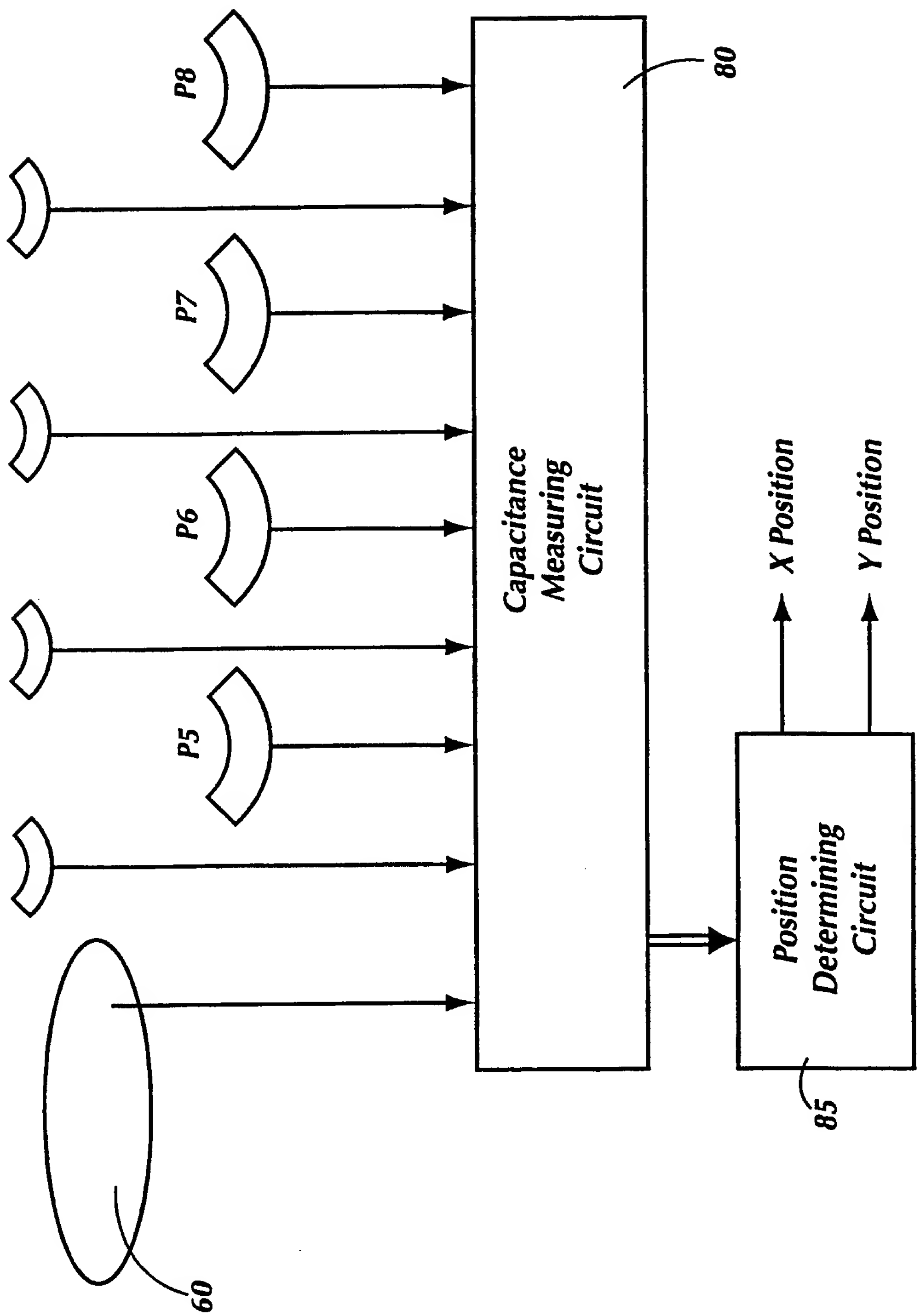
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Fig. 8

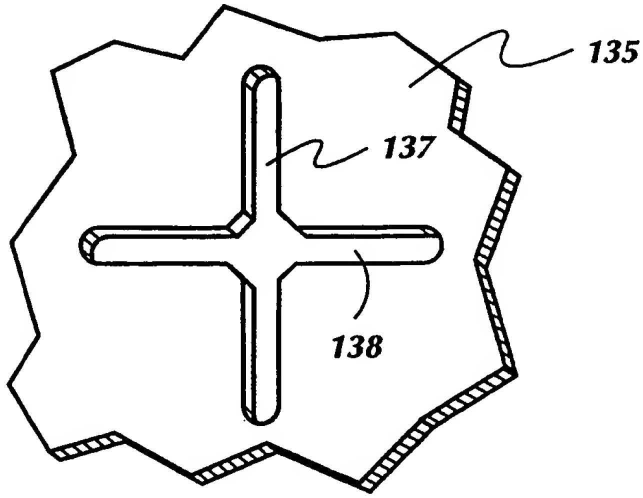
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Fig. 9

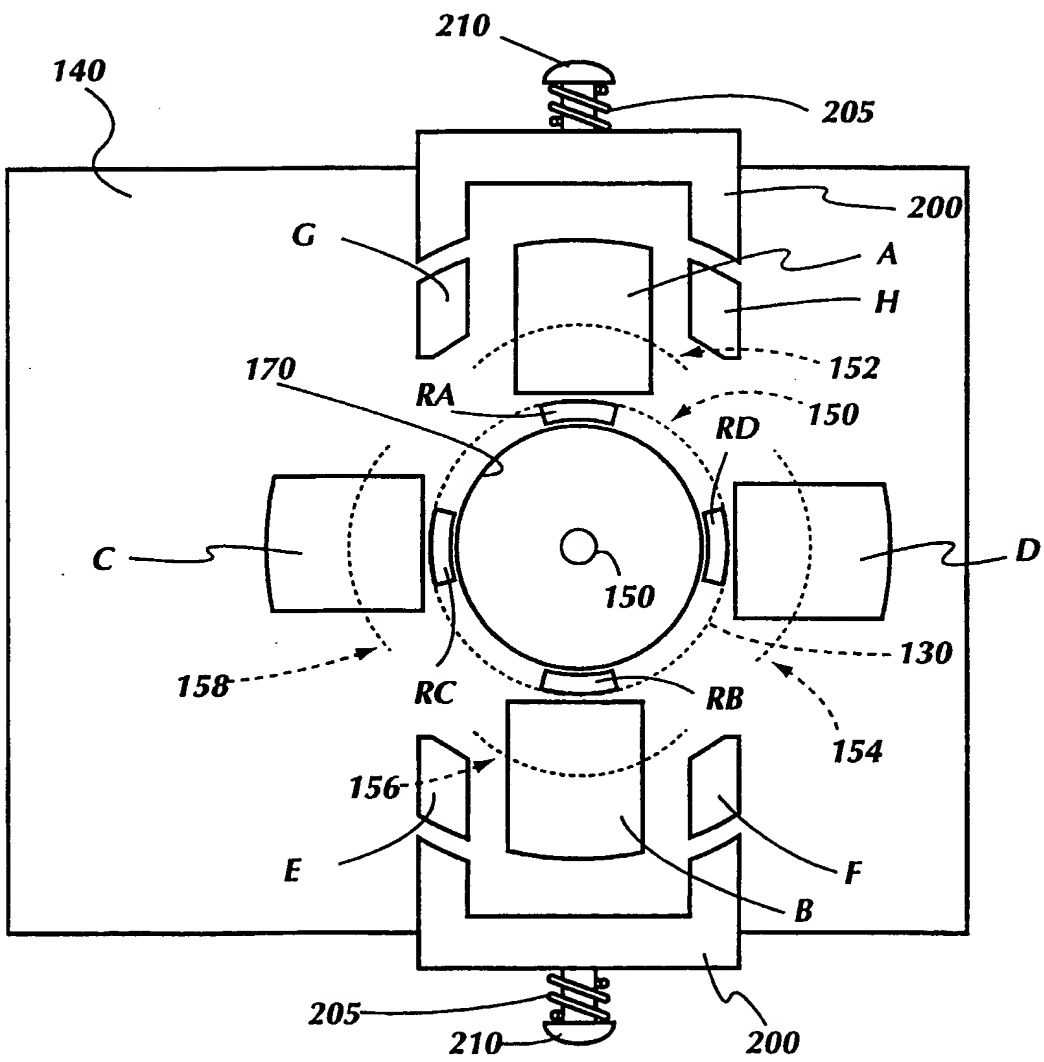
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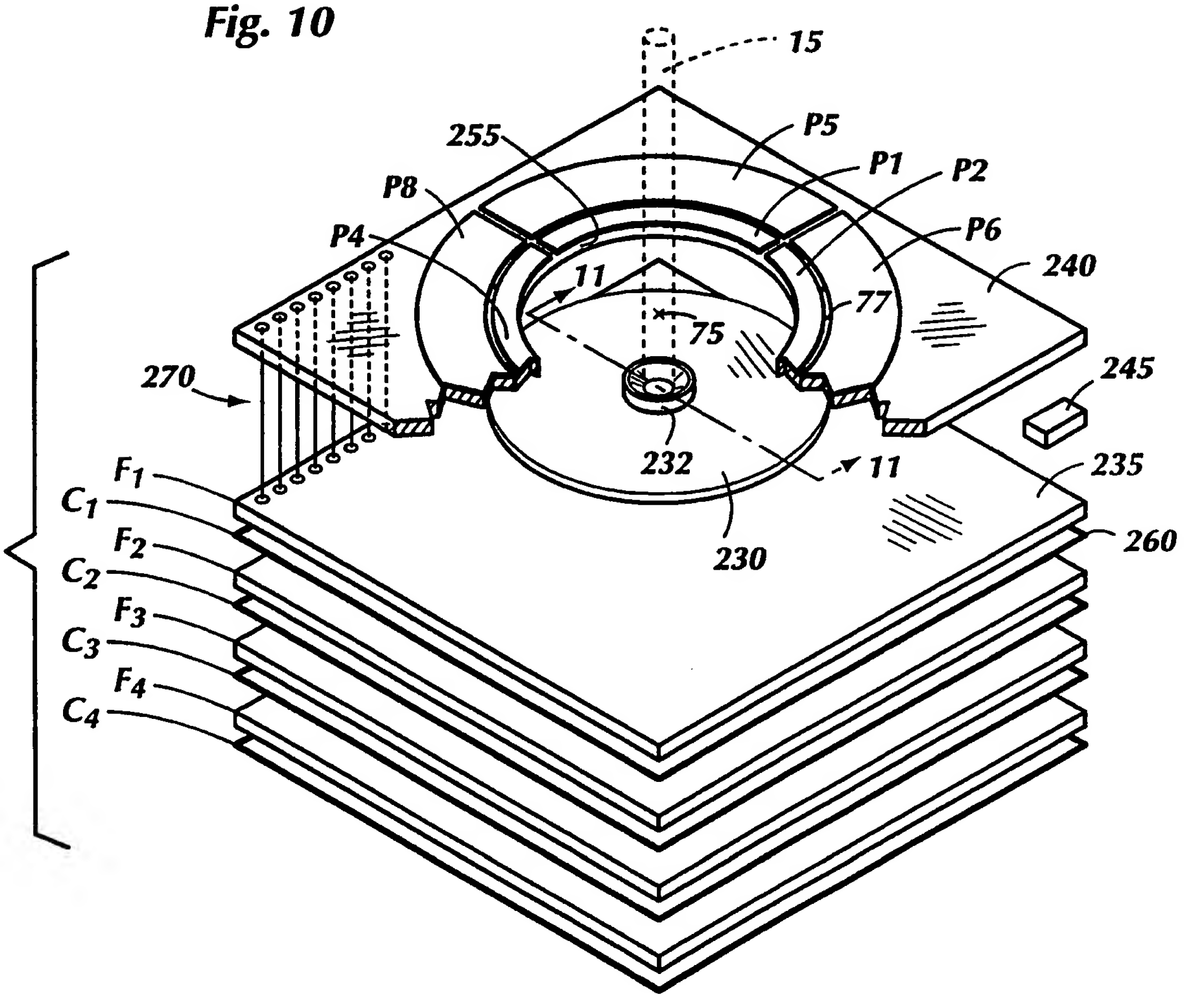
Fig. 10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C_4

Fig. 11

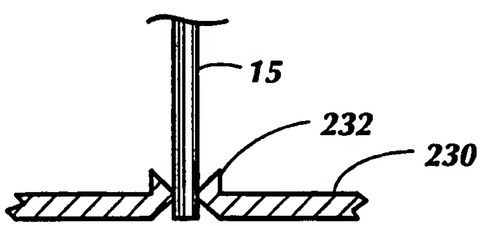
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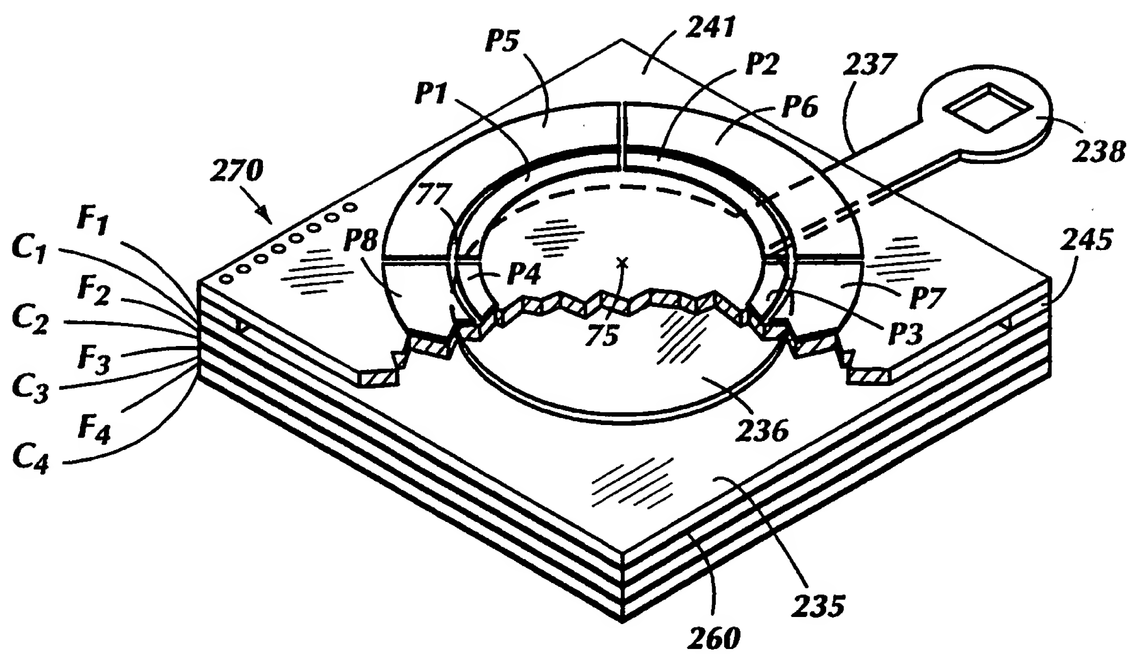
Fig. 12


241
P5
P2
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P1
P6
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F1
C1
P8
245
P4
F2
P7
C2
75
P3
F3
C3
236
F4
C4
235
260

INTERNATIONAL SEARCH REPORT

Int· ional Application No
PCT/US 98/09119

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01D5/241

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01D G01C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 479 191 A (KOMATSU YASUHIRO) 26 December 1995	1-5,9, 10,15, 16,20, 23-28
	see column 5, line 56 - column 7, line 24; figures 1-8	
Y		18
A		12,17, 18,21

Y	US 5 557 495 A (BELCHER DONALD K ET AL) 17 September 1996 see abstract; figure 1	18

	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 August 1998	13/08/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Chapple, I

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INTERNATIONAL SEARCH REPORT

Int·   ional Application No
PCT/US 98/09119

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 525 830 A (RENISHAW PLC) 3 February 1993 see column 2, line 48 - column 4, line 31; figures 1-4 -----	1,3-6, 10-16, 20,22-28

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 98/09119

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		CN 1124375 A	12-06-1996
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EP 0525830 A	03-02-1993	EP 0365644 A	02-05-1990
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